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A Review of Strategies for Sequencing and Synthesizing Instruction

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ABSTRACT. This paper reviews instructional theory and research relating to three design criteria: (a) the order of presentation of instruction (sequencing), (b) the kinds of content relationships that should be taught, and (c) the way content relationships should be taught (synthesis). With respect to sequencing, theory and research on the following are reviewed: scrambled versus logical sequences; micro level sequences such as rule-example versus example-rule and the order of instances in the form of examples or practice; and macro level sequences such as Bruner's spiral approach, Ausubel's general-to-detailed sequence based on "progressive differentiation," Gagne's hierarchical sequence for intellectual skills, the "shortest path" sequence for teaching complex procedures advocated by P. Merrill, Scandura, and others, and the Elaboration Theory's three simple-to-complex sequences proposed by Reigeluth. With respect to synthesis, theory and research are reviewed on Ausubel's advance organizers, Dansereau's networking, Anderson's mapping, Novak's concept mapping, and the Elaboration Theory's synthesizers. Also, research on the relations between sequencing and synthesis is reviewed. A variety of recommendations for future research are provided, and the importance of model building and theory construction are emphasized.

The goal of instructional design as a discipline is to understand and improve methods of instruction. The function of instructional design as an activity, on the other hand, is to decide which methods of instruction should be used under given conditions to bring about desired changes in students. Using an analogy, Reigeluth and Stein (1983) state that the result of instructional design as an activity is an "architect's blueprint" that prescribes what instructional methods should be used for a given objective and a given group of students at a given time; in contrast, the results of instructional design as a discipline are models or theories that provide knowledge about how to produce a good blueprint under various conditions (i.e., various combinations of objectives, student characteristics, and times). This paper, from a discipline point of view, examines the role of sequencing and synthesizing in instruction, as well as different principles, models, or theories that provide strategies for implementing them.

When designing any piece of instruction, two of the important questions facing instructional designers are: (a) How should the instructional events be sequenced over time? (e.g., In what order should the ideas be taught? When should the definitions be given? Where should the practice be placed?), and (b) How should the interrelationships among these ideas be taught to the students? (e.g., How is idea A related to idea B? Where does idea C stand in relation to ideas A and B?). Therefore, strategies for sequencing and synthesizing aim to help instructional designers break the subject matter into small pieces, order the pieces, teach them one at a time, and then pull them together based on their interrelationships.

Two fundamental types of instructional strategies have been identified to provide sequence and synthesis: "macro" strategies and "micro" strategies (Reigeluth & Merrill, 1979). They are different in two ways. First, they differ in the scope of content to which they apply. Instructional designers use macro strategies to organize a set of related skills and knowledge into lessons. So, macro strategies are used to structure a number of different content ideas. Micro strategies, on the other hand, are used to organize stimuli in teaching individual ideas and to structure a set of stimuli for teaching individual facts, concepts, principles, and procedures.

A second difference between macro and micro strategies is the type of "memory" with which they are concerned. Macro strategies are concerned with the organization of memory. Their goal is to create, or effect changes in, the structure of entire skill and knowledge repertoires. Micro strategies, on the other hand, are concerned with memory acquisition: they are designed to efficiently "fill the individual registers" of the student with information. Therefore, the effects of a macro strategy should endure over longer periods of time and should more strongly influence transfer and problem solving than those of a micro strategy. Further, the success of a macro strategy depends to a great extent on the effectiveness of the micro strategy in making the required information available in memory. Because macro and micro strategies deal with different amounts of content and meet different learning needs, they require different techniques for sequencing and synthesizing.

Basically, since sequencing and synthesizing concern, respectively, breaking the content into small elements for acquisition and then pulling it together based on the relationships among these elements, they should have more impact on the macro level of instruction (when teaching more than one content idea—fact, concept, procedure, or principle) than on the micro level (when teaching one content idea). However, sequencing does play an important role in micro-level instruction, where it concerns the order of presenting the generalities, examples, and practice for teaching a particular content idea. Different sequences of these micro instructional events may result in different instructional outcomes.

Given the definitions of sequence, synthesis, macro strategies, and micro strategies, the literature review will take the following form. The sequencing and synthesizing literature will each be discussed in two parts: the first part will discuss the early research and the second will discuss the current research. Finally, some interactions between the two will be examined.

Review of Sequencing Strategies

Before looking at specific studies, it would be helpful to look briefly at the problems involved in sequencing from a theoretical point of view. Two steps are required to construct a sequence. The first is the identification of the elements to be sequenced, and the second is the selection of an organizing principle. Though these two steps may seem trivial, they are not. Given any set of topics, the variety of their elements that may be sequenced and the number of principles that may be

used to create that sequence could generate many macro sequences. Therefore, the first task of the instructional designer is to answer the following two questions: "What is to be sequenced?" and "How will it be sequenced?"

What Is to Be Sequenced?

Surprisingly, most early sequencing research failed to answer this question adequately. It seems, however, that two different views exist. One view maintains that the responses of the learner should be sequenced, and relevant concepts, principles, and procedures should be plugged into the sequence as needed to teach those responses. The other view maintains that the content should be sequenced, and the learner's responses should be included as needed to support mastery of that content.

The difference between these points of view is reflected in the choice of analysis technique used to identify the elements to be sequenced. Resnick (1976) used a figure to represent the "triangulation" among the performance elements, the content elements, and how both impact on the sequence of the instruction (see Figure 1).

Resnick suggested that an analysis focusing on the responses of the learner would identify elements by means of an *empirical* investigation of the performance, whereas an investigation focusing on the content itself would identify elements by means of a *rational* investigation of that content. It appears that versions of one or the other of these two analysis techniques were used in many instructional theories: theories employing a behaviorist approach tend to use empirical analysis (e.g., Gropper, 1973, 1974; Mechner, 1967; Skinner, 1953, 1954); theories employing a cognitive approach tend to use rational analysis (e.g., Bruner, 1966; Landa, 1974, 1983; Scandura, 1973a, 1973b, 1976, 1983). There are also eclectic theories whose approaches of content analysis reflect the use of both techniques (e.g., Gagne, 1977; Gagne & Briggs, 1979; Merrill, 1973, 1983; Reigeluth & Stein, 1983).

How Is It to Be Sequenced?

There are many different ways to organize either performance or content elements. Tyler (1950) identified four organizing principles: logical, psychological, chronological, and part to whole. Thomas (1963) identified five available "rules" for this organization: known to unknown, simple to complex, concrete to abstract, observations to reasoning, and whole to detailed. Each of these sets of principles is

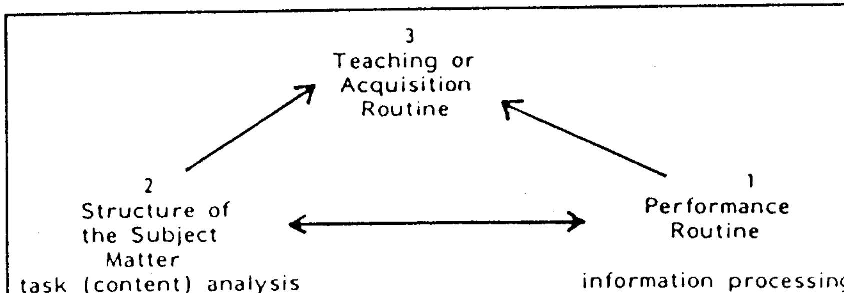

FIGURE 1. Resnick's triangulation of content analysis techniques.

ınstructed from three basic types of principles: those based on the performance, ose based on the content, and those based on the psychology of the learner.

Posner and Strike (1976) presented a scheme for classifying these principles that very similar to that proposed by Resnick (1976) for classifying analysis techniques. ıeir scheme identifies two basic groups of principles: those that are empirically-sed and those that are logically-based. Derived from these two groups are the llowing five categories of principles and numerous subcategories:

1. World-related principles, which prescribe sequencing according to: spatial ations, chronological relations, and physical attributes.
2. Concept-related principles, which prescribe sequencing according to: class ations, propositional relations, sophistication, and logical prerequisite.
3. Inquiry-related principles, which prescribe sequencing according to: the logic inquiry and the empirics of inquiry.
4. Learning-related principles, which prescribe sequencing according to: empir-l prerequisite, familiarity, difficulty, interest, development, and internalization.
5. Utilization-related principles, which prescribe sequencing according to: steps a procedure and frequency of utilization.

Posner and Strike (1976) define the sequences resulting from each category of principles as follows:

1. World-related sequences "are those sequences in which there is consistency ıong the ordering of content . . . and (the) relationships between phenomena as y exist or occur in the world . . ." (p. 672).
2. Concept-related sequences "reflect the organization of the conceptual world content is structured in a manner consistent with the way the concepts mselves relate to one another . . ." (p. 673).
3. Inquiry-related sequences are "those that derive from the nature of the process generating, discovering or verifying knowledge" (p. 676).
4. Learning-related sequences "draw primarily on knowledge about the psychol-y of learning . . ." (p. 677).
5. Utilization-related sequences "can serve as foci for grouping content . . . thin these . . . utilization contexts, content can be sequenced (a) in a way that lects procedures for solving problems . . . or (b) according to the utilization tential for a given content element" (p. 679–680).

Posner and Strike do not suggest that only one type of organizing principle is d to create instructional sequences. Rather, they find that highly sophisticated uencing approaches often employ more than one principle. For example, they cribe Gagne's prerequisite relations in curriculum development as a blend of subcategories: logical prerequisites and empirical prerequisites. Ausubel's "ad-ıce organizers" they describe as "an interesting marriage of concept-related and rning-related bases." However, they contend that it is important to recognize distinction among these principles in curriculum research, evaluation, and nning, since each organizing principle requires a different analysis of content. e scheme developed by Posner and Strike serves as an analytical tool for research sequencing. However, it lacks prescriptive utility for instructional designers in t it contains no guidelines as to which types of sequences are most effective for ich types of content, which kinds of learners, or which instructional outcomes. Given this variety of views of what should be sequenced and how to sequence, now turn to some early research on sequencing.

Early Research—Scramble Studies

If classified according to Posner and Strike, most of the early sequencing research used learning-related principles, specifically behaviorist principles. Because of this behaviorist base, the elements to be sequenced were selected using an empirical analysis of the performance. This body of research was, in essence, empirically based in both the identification of elements and the selection of organizing principles.

The importance of sequencing in instruction was recognized and scientifically examined by B. F. Skinner, who was the first to integrate isolated learning principles into a testable instructional model (Skinner, 1953). His behavioral approach to instructional sequence, based on empirical evidences, has had tremendous influences on the field of instructional design. The principles he proposed stress the contiguity between stimulus and response and contingency of reinforcement, known as the S–R–S chaining. In his advocacy for the use of teaching machines, Skinner contended that subject matter should be broken into small units in order to create a "gradual progression" (shaping of behavior). The principle of gradual progression, along with the principle of S–R–S chaining, dominated the design of instruction for almost two decades. According to Skinner's view, any learning process can be considered as a series of stimulus-response sequences. The prevalence of this sequencing principle is reflected in many instructional theorists' work such as Glaser (1961), Gilbert (1962), Mechner (1967), and Markle and Tiemann (1969).

As the principles of S–R–S chaining and gradual progression were adopted, especially for the design of programmed instruction, some researchers sought to quantify the effects of these sequencing strategies. This early research, called the "scramble studies," tested the effects of a scrambled sequence versus some type of "logical" sequence. However, it is not clear in many of these studies whether they investigated macro or micro strategies. Some of the more famous studies are reviewed below.

Gavurin and Donahue (1961) used a 29-item program on the vocabulary of psychology and randomized items within three blocks. They found that the 20 adult subjects who studied the random sequence made significantly more errors than the 20 adults who studied the logical sequence during the learning period. However, when the criterion test was given one month later, no significant difference was found between the two groups.

Given the lack of significant results, Gavurin and Donahue suspected that the number of frames used in the program might be too small, and the delay of the criterion test might have introduced some leveling effect such that no significant differences could be detected. Following that, Roe, Case, and Roe (1962) conducted a similar study in which they used a longer 71-frame program, and the criterion test was administered immediately after the learning session. The subjects were 36 college freshmen psychology students and the program was on elementary probability. But again, they found no differences between the group receiving the scrambled sequence and the group receiving the logical sequence on the following measures: time to complete the program, errors during learning, the criterion test score, and time required to take the criterion test.

Roe et al. (1962) concluded that careful sequencing of autoinstructional programs might not be necessary for college students since when an out-of-sequence program was presented to them, they became more alert to the material and would deliberately seek more information to answer the questions. They suggested that sequencing in an autoinstructional program may be "a function of such variables as length of program, information content of items, and individual learner differences" (p. 101).

Gavurin et al. and Roe et al. achieved randomization of the sequences by scrambling within blocks. They divided their programs into sub-sequences, and randomized frames only within these sub-sequences. Hamilton (1964) suggested that the lack of sequencing effects from these studies might indicate that "students benefit from having to make organizational efforts within a sub-sequence of frames, as long as the necessary overall sequence of learning material was not disrupted" (p. 259). In our current terminology, what she proposed was that macro presentation structure might have a greater effect on learning than micro structure. Hamilton used fifth- and sixth-grade students and an entirely randomized 106-frame program on music notation, but found no significant differences for sequence on either posttest scores or on the time it took students to complete the program. Hamilton explained that both the brief length of her instructional program and the content she chose might have contributed to her nonsignificant findings. She suggested that perhaps some highly structured content, such as mathematics, might benefit more from sequence than her rather loosely structured content of music notation.

In a previous test of this hypothesis, Levin and Baker (1963) used a 180-item program on the highly structured content of elementary geometry. Since age of the subjects seemed to be an important variable, and subjects in the previous studies were all considered "mature" enough to be able to "unscramble" the sequence, they chose to work with 36 second graders. In a matched-group design, no differences could be found for sequence on tests of acquisition, retention, or transfer. However, Levin and Baker did raise two additional issues: one, that "... the possibility of an interaction between initial ability and treatment effects deserves explicit investigation" (p. 143); and the other, that before prescribing appropriate logical sequence, one must first "... have some empirical generalizations about the relationships between sequential structure, content and dependent variables" (p. 143). In other words, a model was needed.

The relationship between sequence and content was further investigated by Payne, Krathwohl, and Gordon (1967) and was defined as the degree of "logical interrelatedness" inherent in the content. Payne et al. suggested that for sequence to affect learning, the content must have some *inherently* dependent form. To test this, they chose three different sets of math content varying in the amount of this sequential dependency: low, medium, and high. A program of 164 frames on elementary measurement and statistical concepts was given to 195 sophomores. Still, they found no sequence effects on either a test of acquisition or retention. To test Levin and Baker's suggested interaction between sequence and ability, Payne et al. looked at the correlation between students' MSU Arithmetic Test scores and both acquisition and retention test scores. Again, no pattern could be found to suggest that students of high ability could compensate for lack of sequence or that students of low ability could not compensate. However, Payne et al. explained that a few possible biases might have been introduced during the process, such as some redundancy or repetition of the information in the instruction, so that even with the scrambled sequence, one frame might still contain cues to the meanings of

others, thereby reducing the actual differences between the scrambled and logical sequences.

In a different type of scramble study, Buckland (1968) was the first researcher to differentiate between micro and macro sequences. He used a 55-frame mathematics program sequenced in three ways: standard form, 10 randomized blocks of content, and all frames in random order. Essentially, Group 1 received a logical sequence, Group 2 received a randomized macro sequence with a logical micro sequence, and Group 3 received randomized micro and macro sequences. Buckland found that for low ability students, the logical program group was significantly better than either of the scrambled groups on the transfer test and significantly better than the item-scrambled group (Group 3) on the acquisition test. In contrast, for the high ability students, the only significant difference was found on the acquisition test where the block-scrambled group was significantly better than the item-scrambled group. In fact, the block-scrambled group scored highest in both the acquisition and the transfer tests for high ability students. An interaction between sequence and ability seemed to appear here (see Figure 2), which suggested that low-ability students benefitted from a correct sequence, whereas high-ability students did not necessarily.

How was it that Buckland was able to find significant sequence effects where so many had failed? Buckland suggested that as the subject sample included only "boys from the first year of a boys' secondary school" (12 years of age; p. 199), his results would be difficult to generalize. However, some measure of generalization is justified in that Buckland felt the boys of high ability were similar to the college students and adults used in the earlier studies in that they possessed a "flexibility and adaptability in mentally rearranging material" (p. 203). He suggests, then, that his results are real. An alternative explanation of his results lies in the fact that the two scrambling methods used (i.e., micro and macro) were unique to this study.

Though the specific nature of Buckland's measures was not identified, a check of Buckland's tests suggests that they did test the students' abilities to *remember* the generality of an idea and to *apply* it to previously unencountered instances (Merrill, 1983). From this pattern of results, it is possible to infer that micro sequence affects remember-level outcomes and, if the effects of micro and macro sequencing are additive, macro sequencing affects use-level outcomes (application). Though the types of sequences and outcomes tested by Buckland are similar to those of current interest, Buckland did not present a clear definition of the

	STANDARD vs MACRO SCRAMBLING	STANDARD vs MICRO AND MACRO SCRAMBLING
TRANSFER (use)	N.S.	SIG.
ACQUISITION (remember)	SIG.	SIG.

(Low ability students only)

FIGURE 2. Pattern of differences from Buckland's study.

"standard" sequencing principle used, of the content elements sequenced, or of the specific instructional outcomes being measured.

Summary

One can see from the preceding review that there are no conclusive results from the scramble studies. The researchers' consistent conclusion is that sequencing depends on many variables. Four major problems can be identified to account for the inconsistency of research findings. First of all, what was sequenced was not clearly delineated in these studies. Secondly, most of the early studies did not differentiate between macro or micro levels of sequencing. This made it difficult for other researchers to replicate the studies and for instructional designers to draw implications for practice. Thirdly, most researchers did not differentiate among different types of instructional outcomes when measuring the effects of sequencing. Finally, no precise organizing principles were followed. The sequences used were either based on imprecise learning-related principles or hazy content-based principles such as "logical interrelatedness."

Therefore, as suggested by R. Anderson (1967), Niedermeyer (1968), Heimer (1969), and Natkin and Moore (1972) in their reviews of sequence-related literature, for sequence effects to be consistently found, a *theory of sequencing* must be formulated with a set of testable hypotheses for identifying elements to be sequenced and for determining principles of sequencing in relation to different content, learner, and outcome variables.

Current Research

In this section, review will be divided into two parts: micro sequencing, which discusses the theoretical development in ordering instruction for teaching individual ideas; and macro sequencing, which examines various approaches for ordering multiple ideas in course/curriculum design.

Micro Sequencing

Merrill, Reigeluth, and Faust (1979) were among the earliest who identified the major content elements for micro sequencing. The Component Display Theory (Merrill, 1983; Merrill et al., 1979) proposes four different "primary presentation forms" for micro sequencing. These four presentation forms answer the "What is to be sequenced?" question on the micro level.

Merrill and his associates suggest that the "grist" of instruction is composed of two elements: generalities and instances. A generality is a definition or rule, and an instance is an example of the definition or rule. For example, a generality for the concept *photograph* might read: "any graphic rendering, usually on paper, resulting from the action of light on light-sensitive chemicals." An instance of the above generality would be an actual photograph.

Merrill et al. also suggest that generalities and instances can be presented to the students in two ways: expository (e.g., Here is an example of . . .) or inquisitory (e.g., Is this an example of . . .?). Therefore, the four primary presentation forms are: (a) generality in an expository form, (b) generality in an inquisitory form, (c) instance in an expository form, and (d) instance in an inquisitory form. Any generality or instance presented in an inquisitory form can be considered as a

practice or test item, and any instance presented in an expository way is considered an example. Micro sequences then are achieved by ordering the above four presentation forms.

The theory also suggests that a variety of "secondary presentation forms" can be embedded in the sequence to aid learning. These aids include mnemonics, mathemagenic help, alternative representations, feedback, and others. Component Display Theory provides a language as well as a taxonomy of variables for systematic investigations of the effects of different sequences at the micro level.

Based on the Component Display Theory, three major events have been identified in the teaching of a single "piece" of content to attain "use-a-generality" outcomes (such as concept attainment). They are: the presentation of a generality (definition or rule), the presentation of examples (and sometimes nonexamples), and the availability of practice with feedback (Merrill et al., 1979). Any single micro sequence is defined by the organization of the above three events. Different micro sequences represent different instructional approaches and have been shown to result in different instructional outcomes. For example, building on the "rul-eg" versus the "eg-rul" line of inquiry (Evans, Homme, & Glaser, 1962), a generality-example or rul-eg sequence (which defines an expository approach) results in better use-a-generality outcomes (near transfer), whereas an example-generality or eg-rul sequence (which defines a discovery approach) results in better find-a-generality outcomes (far transfer), according to Guthrie (1967), Roughead and Scandura (1968), Scandura, Woodward, and Lee (1967), and Hayes-Roth (1977).

But the sequencing of generalities and instances is not the only kind of micro-level sequencing of concern to instructional designers. Also important is the sequencing of instances themselves. Three principles for the selection and sequencing of instances have been identified. First, Tennyson and his associates (Park & Tennyson, 1980; Rothen & Tennyson, 1978; Tennyson, 1972, 1975, 1980; Tennyson & Boutwell, 1974; Tennyson, Steve, & Boutwell, 1975) investigated a strategy for organizing sets of examples and nonexamples where examples and nonexamples of a concept are matched to highlight the concept's critical attributes. In this matching, examples and nonexamples are chosen with their noncritical attributes as similar as possible while one critical attribute is varied. Markle and Tiemann (1969) proposed a similar principle of matching examples and nonexamples, and labeled the set that manifested the above characteristic "rational set." Klausmeier (1980) shared the same notion of matching examples and nonexamples when teaching concepts, but suggested that complex matching may not be necessary when a set of concepts is to be taught where examples of one concept are nonexamples of the other.

The second principle in organizing examples suggests that successive examples should be as divergent as possible (Merrill, Olson, & Coldeway, 1976). This is done by varying the noncritical attributes as much as possible within the examples. Thirdly, it is suggested that the examples should represent a range of difficulty and be presented in an easy-to-difficult order (Klausmeier & Feldman, 1975; Merrill et al., 1976).

Macro Sequencing

A great many of the prescriptions about sequencing are at the macro level. Some of the sequencing strategies widely known to instructional designers include: spiral curriculum (Bruner, 1960), progressive differentiation (Ausubel, 1963, 1964, 1968) and hierarchical sequence (Gagne, 1968, 1977). Others, such as shortest path (P. Merrill, 1978; Scandura, 1973a, 1973b, 1976, 1983), and elaboration (Reigeluth & Stein, 1983), though less widely known, have yielded promising results. These strategies will be reviewed in the following section. There are a variety of other sequencing strategies, such as backward chaining (Gilbert, 1962), the "snowball" approach to teaching algorithms (Landa, 1974, 1983), and static and kinetic structure (O. Anderson, 1966, 1969, 1971), which have received less attention among instructional designers and, therefore, are not reviewed here.

Spiral curriculum. Bruner proposed that content should be introduced commensurate with the students' intellectual development throughout their entire educational process and should be built around the crucial ideas in the subject (Bruner, 1960, 1966). The spiral approach suggests that the same crucial ideas of a subject be taught at each grade but with increasing degrees of complexity and sophistication. The periodic recycling of the same topics with progressively greater complexity functions like a spiral.

Bruner suggests that if a subject is important for the student to know, it should be introduced as early as possible in the student's education. Let the subject be developed and redeveloped as the student becomes more intellectually mature and can grasp the substance of it. Bruner contends that the continuous exposure of the student to the topics facilitates a deep and more intuitive understanding of the subject.

Unfortunately, this approach can be difficult for an instructional designer to implement because Bruner did not provide enough guidance as to how to create a spiral curriculum. Therefore, it is not clear how the subject should be taught at various stages in the spiral.

Progressive differentiation. Ausubel constructed an instructional theory based on his theory of learning that assumed that learners' cognitive structures are "hierarchically organized in terms of highly inclusive concepts under which are subsumed less inclusive subconcepts and informational data" (1960, p. 267). His instructional theory proposed a sequence that organized content into levels of detail that approximated the way people naturally learn. That is, Ausubel believed people tend to "subsume" detailed information under more general types of information. Therefore, Ausubel advocated a general-to-detailed or "top-down" sequence in which general and inclusive ideas ("advance organizers") were presented first, followed by related ideas of greater specificity and detail that provide "progressive differentiation" of the more general and inclusive "anchoring" ideas, and which in turn serve as advance organizers for the next level of detail and specificity.

Ausubel's instructional theory was primarily targeted at the social sciences or other highly conceptual, verbal types of content. For highly structured content such as mathematics, his general-to-detailed sequence has not been rigorously examined. Also, like Bruner, he did not provide enough guidance as to how to create a general-to-detailed sequence based on the notions of advance organizers and progressive differentiation. Hence, although designers and theorists have benefitted from Ausubel's instructional theory in general, his sequencing principle has been very difficult for instructional designers to implement.

The effectiveness of Ausubel's sequencing strategy has been tested to some degree by many advance organizer studies, for advance organizers represent more general

and inclusive ideas that are taught prior to more detailed and specific ideas that progressively differentiate them. Several reviews of those studies have been conducted (Barnes & Clawson, 1975; Lawton & Wanska, 1977; Luiten, Ames, & Ackerson, 1980; Mayer, 1979a). Results indicate that such a sequence is beneficial when unmastered prerequisite knowledge and abilities are important components of the content and when transfer is an especially important outcome (Mayer, 1979a).

Hierarchical sequencing. Gagne (1968) suggested that content could be analyzed into hierarchical form. His "learning hierarchy" was formed by breaking intellectual skills into simpler component parts. The sequence derived from this analysis, then, used a "parts-to-whole" organizing principle. This sequence follows the hierarchy in a "bottom-up" manner where the most elemental parts at the bottom of the hierarchy are taught first; then the more complex combinations of the parts are taught later. In validations of his hierarchical sequencing technique, Gagne (1962; Gagne & Paradise, 1961) found that teaching the prerequisite knowledge first seems to facilitate the learning of the higher order skills better than teaching the prerequisite knowledge out of sequence.

In another study of the effects of hierarchically sequenced instruction, Pyatte (1969) could not find any significant main effects attributable to sequence. However, he did find a significant and interesting interaction between sequence and ability, with students of low ability doing better on an acquisition test using the unstructured program and students of high-ability doing better on the test using the hierarchically structured program. No such interaction was found on the transfer test. As previously mentioned, Buckland (1968) found an opposite effect in a scramble study and attributed its cause to the high ability students' "flexibility and adaptability" in organizing instruction mentally. Pyatte agreed that the interaction he found was unusual but argued that no bias was introduced in the study, therefore, "There was no reason to believe that the underlying distributions of the variables used in this study departed enough from a normal distribution to account for the interaction observed" (p. 259).

Niedermeyer (1968), and Niedermeyer, Brown, and Sulzen (1969) tested three hypotheses identified in the scramble studies but included a hierarchical analysis to identify and sequence the content elements. Their hypotheses were: (a) Sequence effects depend upon the structure of the subject matter, (b) Sequence effects depend upon the individual learners's ability, and (c) Sequence effects depend on the age of the learner. They attempted to test these hypotheses by assigning ninth-grade students to one of three 110-frame algebra programs taken from Gagne and Brown's Number-Series Program (1961). The three sequences are Logical order, Scrambled, and Reverse order. IQ was used as a measure of ability. They found no main effects for sequence, nor were there any IQ × sequence interactions on scores for either a retention or a transfer test. The authors concluded, therefore, that "what is learned is more crucial than how it is learned" (Niedermeyer et al., 1969, p. 66). They suggested that the greatest attention should be given to the identification of content rather than to the organizing principles used to sequence that content.

That the results of these studies were inconclusive may be due to two factors. First, the instructional treatments were relatively short—usually under one hour. It is thought that most competent learners are able to organize information over short periods of time. If this were the case, then macro sequencing strategies would only become effective in longer instructional programs.

Secondly, these studies did not test the interaction between content and dependent variables as proposed by Levin and Baker (1963), and Reigeluth, Merrill, and Bunderson (1978). The dependent variables are learning outcomes that may be remembering, using, or finding, as suggested by Merrill (1983), or, respectively, may be verbal information, intellectual skills, or problem solving, as suggested by Gagne and Briggs (1979). If the dependent measures used in these studies were not sensitive to these or other comparable differences in outcome, then any effects of sequence might have been hidden.

Brown (1970) continued to investigate the effects of hierarchical sequence in relation to learner abilities (IQ) and included different instructional outcomes. He hypothesized that if the conclusions of the Niedermeyer et al. (1969) study are correct, sequence should not be an important factor for a short instructional program used by fairly bright learners. The Gagne and Brown (1961) Number-Series Program was used again, which consists of two parts. The first 89 frames are introductory, presenting the basic concepts and skills necessary for achieving the final objective. The remaining 41 frames gradually guide the students until they discover a higher order principle. In comparing the logical sequence group, which received the program in a hierarchical sequence, with the scrambled group, in which each student received a different random sequence, Brown found no significant effect for sequence on learning "rote," lower order principles (Gagne's verbal information). Nor did he find a significant IQ × sequence interaction. However, for the higher order problem-solving outcomes, the hierarchical sequence was superior for both low- and high-ability students. The hypothesis that high-ability students could unscramble the short program was not supported. Brown (1970) quotes Gagne (1968) in saying, "For problem-solving tasks, the skills have an ordered relation to each other such that subordinate ones contribute positive transfer to superordinate ones" (Brown, p. 44). In other words, a hierarchical macro sequence facilitates the learning of higher order skills. Brown concludes that if the tasks are at a lower level, such as Gagne's verbal information, macro sequence may make little difference even if the instruction is fairly long. On the other hand, if the tasks are at a high level, such as Gagne's problem-solving level, sequence can have an important effect upon all learners, even if the instruction is fairly brief.

Shortest path sequencing. Many information-processing analyses employ "path analysis" in sequencing the content. Paul Merrill (1978, 1980) is among the earliest who argue that if a subject is algorithmic (procedural) in nature, the sequence of teaching it can be determined by identifying the specific operations involved and the unique paths through the performance. This is done by first conducting an information-processing analysis that results in a list of operations in order of actual performance. Then, the designer selects the set of operations that constitute the "shortest path" to a successful performance. The whole instructional sequence consists of a series of sets of operations (paths) that are progressively longer (i.e., progressively more operations in each path). Thus, as the instruction proceeds, the procedure or rule, as it is known to the learner, becomes more and more complex with more and more detail.

Along the same line, Scandura (1971, 1973a, 1983) employs path analysis in identifying the "atomic" components of a rule. In his Structural Learning Theory,

Scandura proposes that any problem domain can be represented in terms of a finite set of rules, each of which can be represented in terms of a finite number of elemental, "atomic" components. For each rule, there is a number of distinct paths that are made of a number of atomic components. He contends that for instruction to be efficient, the teacher should first determine what the learners already know about the rule by identifying the paths they have already mastered, and then should teach only those paths they failed to perform successfully or have not learned. The sequence is then formed by arranging the unmastered paths in a simple-to-complex sequence. Note that path analysis is only applicable to procedural content.

Elaboration sequencing. The Elaboration Theory (Reigeluth & Stein, 1983) proposes an elaboration approach to macro sequencing, which is a special kind of simple-to-complex sequencing. Though the aforementioned sequencing approaches employ variations of the simple-to-complex organizing principle, the elaboration sequence has two unique features: (a) the most general ideas *epitomize* rather than summarize the whole subject, and (b) there are actually three different sequences, each based on one *single* content orientation (i.e., concept, procedure, or principle). In principle, the first lesson in the sequence includes the simplest ideas and is called the *epitome* lesson. Reigeluth (1979) states that the epitome epitomizes the whole subject by presenting a few of the most crucial ideas at a concrete, application-based level. The ideas used to construct the epitome are fundamental, representative, simple, and general, but not abstract. Thus, the learners are required to learn the ideas at the *use* level rather than at the *remember* level. The Elaboration Theory also recognizes the need for different sequencing strategies for different content orientations. The content orientation chosen for each subject should be based on whether the instructional outcomes focus primarily on the learners knowing *what, how*, or *why* vis-à-vis the subject.

The basic elaboration sequence for any of the three orientations is analogous to a zoom lens in that the epitome presents the most inclusive, "wide-angle" picture. Then in the subsequent lessons, the instruction "zooms in" on each one of the major ideas, revealing more detail on each of them. During the process, the instruction periodically "zooms out" to review the wide-angle picture and to preview it for selecting the next target for "zooming in."

The elaboration sequence can be seen as an integration of many of the major sequencing strategies. The basic framework has been provided by Ausubel's subsumption theory and Bruner's spiral curriculum. Their approaches are reflected in the elaboration sequence by the simple-to-complex arrangement of content ideas and reiterations of the same ideas with progressive degrees of detail and complexity.

With regard to different content orientations, the elaboration approach is based on the notion that the nature of the simple-to-complex sequence must differ depending on the kind of content that is considered to be most important to the goals of the instruction. If *concepts* are most important (addressing the *what* as is usually the case in an introductory biology class), then the concepts are organized into taxonomies of kinds or parts. The instructional sequence is formed by selecting the most important, comprehensive, and fundamental structure and sequencing its concepts from the top down (i.e., from the most general concepts to progressively more detailed and less inclusive concepts). Other types of content such as concepts, facts, procedures, and principles, along with learning prerequisites (Gagne, 1968) are "plugged into" that sequence at the point where each is most relevant (Reigeluth & Darwazeh, 1982).

When *procedural* content is the most important (addressing the *how* as in an English composition course), then the simple-to-complex sequence is achieved by identifying the simplest possible version of the task (equivalent to Paul Merrill's path analysis procedure) and gradually adding more complex paths. Other types of content are then "plugged into" that sequence at the point where each is most relevant (Reigeluth & Rodgers, 1980).

When theoretical content is the most important (addressing the *why* as in an introductory economics course), then the simple-to-complex sequence is formed by first identifying all principles that should be taught and then prioritizing the principles according to their criticality by continuously asking the question "What principles would you teach if you had the learners for only one hour?" Other types of content then are "plugged into" that sequence at the point where each is most relevant (Reigeluth, in press; Sari & Reigeluth, 1982). This sequence, as it turns out, is usually very similar to one arranged in a historical order (the chronological order by which these principles were discovered in the discipline).

Although the elaboration provides great detail for the operationalization of its principles, many of the prescriptions for this sequencing strategy have not been empirically tested.

Summary

Much research effort has been devoted to investigating the effects of sequencing at the *micro* level. Merrill's (1983) Component Display Theory provides a theoretical paradigm that identifies the elements for sequencing and integrates many findings from research into five specific prescriptions regarding micro sequencing. Those prescriptions are: present the generality before the examples for use-a-generality outcomes (near transfer); present the examples before the generality for find-a-generality outcomes (far transfer); arrange instances (examples and practice) in a divergent sequence (i.e., make successive examples different from each other); arrange instances (examples and practice) in an easy-to-difficult sequence; and provide nonexamples "matched" with examples (i.e., as similar as possible and accompanying them).

Research on sequencing at the *macro level* has been growing for the past two decades. Bruner's spiral approach, though among the first to address the problem of sequencing, has not received any experimental study to our knowledge and has not been accompanied by specific guidelines on how to create it. Ausubel proposed a general-to-detailed sequence based on progressive differentiation so that knowledge of greater specificity and detail is "subsumed" in learners' memories under more general and inclusive "anchoring" ideas. His sequencing strategy has received considerable research support for transfer outcomes and hierarchically related content, but, like Bruner, Ausubel has not provided detailed guidelines on how to design his sequence.

Gagne advocated the idea of hierarchical analysis and sequencing of intellectual skills so that simpler component skills are taught before the more complex combinations of those parts. Research has shown that in skill learning, such learning prerequisites do indeed exist and, concomitantly, that a hierarchical sequence is beneficial for such situations.

For procedure learning, Paul Merrill, Scandura, and others have prescribed a shortest path sequence for teaching complex procedures (i.e., procedures with a variety of branches). Various theories have provided detailed guidelines on how to design this kind of sequence, but we were unable to find any empirical research on it.

The Elaboration Theory proposes three simple-to-complex sequencing strategies and a basis for prescribing which sequence to use when. It represents an integration and extension of all the macro approaches reviewed above. For all three strategies, it prescribes a simple-to-complex sequence that epitomizes the course content (i.e., it teaches the most important, representative, basic ideas at a use-a-generality level first) and then proceeds to elaborate on that content one level at a time. The nature of the simple-to-complex sequence is different (conceptual, procedural, or theoretical) depending on the purpose (or orientation) of the course. Detailed guidelines have been provided on how to design each of these three sequences, but again, little research has been conducted on its effects.

Of the empirical research conducted to date, it appears that micro sequences have a much greater impact on learning than macro sequences. This may be due to the fact that the two basic questions concerning sequencing (what is sequenced and how is it sequenced) have been answered for micro sequences but not for macro sequences.

For micro sequences, the research is consistent in its conclusions that three components are required for an *effective* sequence: a generality, an example, and practice. Most current research concerns *how much* of these three are required and not *whether* they are required (Park & Tennyson, 1980). Therefore, micro-sequencing research has progressed to the point where it is mostly concerned with instructional *efficiency* rather than instructional effectiveness.

Macro-sequencing research on the other hand has yet to sufficiently answer the "what is sequenced?" or "how is it sequenced?" questions, and has not resulted in a useful model of sequencing. Regardless of the instructional elements identified (e.g., behaviors, rules, concepts) and of the organizing principles used to sequence those elements (e.g., top-down, bottom-up, shortest path), no consistent instructional benefits have been attributed to macro-sequencing strategies. This may be due to a number of reasons, including:

1. Macro sequences really do not make a significant contribution to learning, i.e., most learning is due to micro sequences.
2. Researchers have not yet successfully identified the important sequencing variables nor have they modelled their interactions.
3. Empirical evidence has not yet been collected for sufficiently large blocks of instruction, because sequencing makes negligible differences for small amounts of content.

Until the research offers better models for macro sequencing, the suggestion for instructional designers is to become proficient with a variety of task and content analysis methodologies as well as sequencing strategies that employ the results of those analyses.

Review of Synthesizing Strategies

As mentioned before, synthesis is considered a macro strategy rather than a micro strategy. The interest in synthesizing content grew out of an interest in the structure of the content. Bruner (1960) typified this interest when he wrote, "Grasping the structure of a subject is understanding it in a way that permits many other things to be related to it meaningfully" (p. 7). To learn structure, in short, is to learn how things are related. However, there are many different ways in which things may be related. Though there may be disagreements regarding how synthesizing strategies should work and what they should look like, researchers have one recognition in common: synthesizing concerns the structure of the content. This structure is thought to affect learning in two ways: first, as an efficient vehicle for learning content ideas, and second, as an important aspect of content in its own right (see Schwab, 1962).

There are two points of view concerning the structure of content. The first point of view assumes that content structure is "domain dependent," meaning it is different for each subject (i.e., math, social studies, etc.). The second point of view assumes that structure is "domain independent" and is identified through a standard content analysis. Schwab (1964) illustrated the first point of view by attempting to identify the structure of the natural sciences. He used a technique that identified the kinds of principles these sciences employ (i.e., reductionist, holistic, and rational) and then defined the structure of these sciences as a web of different types of principles. Similarly, Scriven (1964) analyzed the structure of the social sciences and suggested a structure that resembled a pyramid of hierarchically related concepts.

The second point of view, that content structure is domain independent, was illustrated by Gagne (1968), who suggested that all intellectual skills, regardless of domain, can be arranged into a hierarchical structure. Along the same line, Reigeluth, Merrill, and Bunderson (1978) suggest that there are five basic structures, one for each of the following types of content. The content types and their associated structures are: (a) *facts* are organized into *lists*, (b) *subsets* are organized into *taxonomies*, (c) *concepts* are organized into *learning hierarchies*, (d) *steps* are organized into *procedural hierarchies*, and (e) *principles* are organized into *models* (p. 122).

Clearly, there is merit to both points of view: structure as domain dependent and as domain independent. Any comprehensive approach to teaching relationships (structure) must utilize both, as the goal of synthesis is to teach such relationships to the learner. However, only a few strategies have been developed to achieve synthesis.

Early Research

One of the earliest and most famous of these strategies was the advance organizer proposed by Ausubel (1960). To test his strategy, Ausubel developed a 2,500-word passage describing the metallurgical properties of steel and two 500-word "organizers": one that dealt with the content at a "much higher level of abstraction, generality and inclusiveness" and a second that "consisted of such historically relevant background materials as the historical evolution of the methods used in processing iron and steel" (1960, p. 268). The first organizer was given twice to one group of students, and the second was given twice to a second group. Ausubel found that, on a retention test administered three days after the administration of the learning passage, the group given the abstract organizer scored significantly higher than the group given the historical organizer. To find out if the organizer

contained enough information to account for this increased level of learning, Ausubel administered just this organizer to a comparable group of students and found they did not score above chance on a retention test. Ausubel concluded that an organizer of this type can provide a meaningful framework to which the learner can relate the subsequent instruction.

Ausubel followed this study with two more (Ausubel & Fitzgerald, 1961, 1962) to test the effects of advance organizers and existing knowledge on the learning of a related but different topic. He proposed a second type of organizer, a "comparative organizer," to be distinguished from the previous "expository organizer," which should be used in teaching a new concept when students are already familiar with a generally related but different one. This comparative organizer, as Ausubel prescribed, functions to "delineate clearly, precisely and explicitly the principal similarities and differences between the new learning passage and existing, related concepts in cognitive structure" (Ausubel & Fitzgerald, 1961).

The principles from his Theory of Meaningful Verbal Learning (Ausubel, 1963) led Ausubel to assume that the synthesis of ideas could be achieved by using these advance organizers, which provide a meaningful context for subsequent learning. Strictly speaking, however, the organizer is not a synthesis of ideas because it does not explicitly teach the structure of the content. It is the learner who must identify the relationship between the new ideas and the more general and inclusive anchoring ideas. Nevertheless, it seems that synthesis often occurs. The synthesis effects of the expository organizer may be due to the fact that the short period of time between the presentation of the organizers and the presentation of the new materials makes it relatively easy for many learners to discover the relationships. Mayer (1976, 1979b) suggested that organizers "activate . . . the meaningful learning set during learning" (1976, p. 143). The synthesis effects of the comparative organizer might be due to the learner's "borrowing" of a relevant set of content interrelationships from previously learned material, as in the case comparing Buddhism with Christianity (Ausubel & Fitzgerald, 1961).

Because advance organizers do not explicitly identify the interrelationships among content ideas, many learners may not make the connection. Hence, it is more appropriate to think of organizers as a type of pre-instructional strategy rather than a type of synthesizing strategy. Pre-instructional strategies are groups of content given before a lesson that seem to alert, inform, prepare, or clarify to the student what is about to occur during instruction (Hartley & Davies, 1976). Through this process, students are sometimes able to infer an appropriate set of content interrelationships that aid in meaningful reception learning.

Summary

Early research on synthesis effects is inconclusive. The theories dealing with domain dependent structures (e.g., the structure of the social sciences) have not been empirically tested. The theories dealing with domain independent structures (e.g., hierarchies) have been tested, but not in the context of synthesis.

One domain independent strategy, the advance organizer, has been tested as a synthesis strategy. However, the results of this research are in doubt because no operational definition for creating an advance organizer is provided that permits replications of research. Therefore, for those studies that present significant advance organizer effects, it is not clear what attribute of the organizer is responsible for the effects.

Current Research

Current research on synthesis effects has attempted to answer two questions similar to those of sequencing research: "What are the elements of content structure?" and "What is the principle used to synthesize those elements?". Perhaps not surprisingly, the most often identified elements of content structure are the same as those identified for instructional sequences, namely, concepts, procedures, and principles.

Most research has investigated domain independent principles—specifically, different types of content "networks" that graphically illustrate the interrelationships among content elements. Three different network strategies have been suggested for synthesizing primarily conceptual content: networking, mapping, and concept mapping. A fourth strategy, the "synthesizer" presented in the Elaboration Theory, is suggested as an alternative strategy capable of synthesizing concepts, procedures, and principles.

Networking

As early as 1969, Quillian proposed a network structure of memory in his design of a computer program that could be taught to "comprehend" text. The basic idea of the memory structure is that every concept or idea is stored as a "unit" in the memory. Relating to that unit are a number of properties that can be used to describe it, and a number of "supersets" that contain more general concepts/ideas that subsume the unit. This intralinked structure of units is reorganized and adapted every time a new piece of information is introduced and broken into discernible units or properties to be recombined with the existing memory network.

Later, as more network models of memory were proposed (e.g., J. Anderson, 1972; Bobrow & Winograd, 1977; Rumelhart, Lindsay, & Norman, 1972), they provided a theoretical basis for many instructional researchers to advocate the use of networking as an effective strategy for teaching the content relationships. Basically, networking requires students to identify the important concepts or ideas in the text and to describe the interrelationships among these ideas in the form of a network diagram using nodes (for concepts) and links (for relationships; see Figure 3).

Dansereau and his associates (Dansereau, 1978; Dansereau, McDonald, Collins, Garland, Holley, Dickhoff, & Evans, 1979) identified three types of relationships among content ideas: hierarchy structure (type or part relationship), chain structure (procedural or causal relationship), and cluster structure (characteristic, analogous, or demonstrative relationship). Dansereau asserts that students' application of this networking technique will result in their improved comprehension and retention of the material since the network diagram provides a visual, spatial organization of the information and helps the student see an overall picture of the material. In addition, the terms describing the relationships depicted in the network can serve as a language for the students when exploring the memory during retrieval of information. For example, Dansereau wrote, "Is the information I am looking for a *lead to* chain? Is it *part* of a larger concept? Is it an *example* or *type* of a more

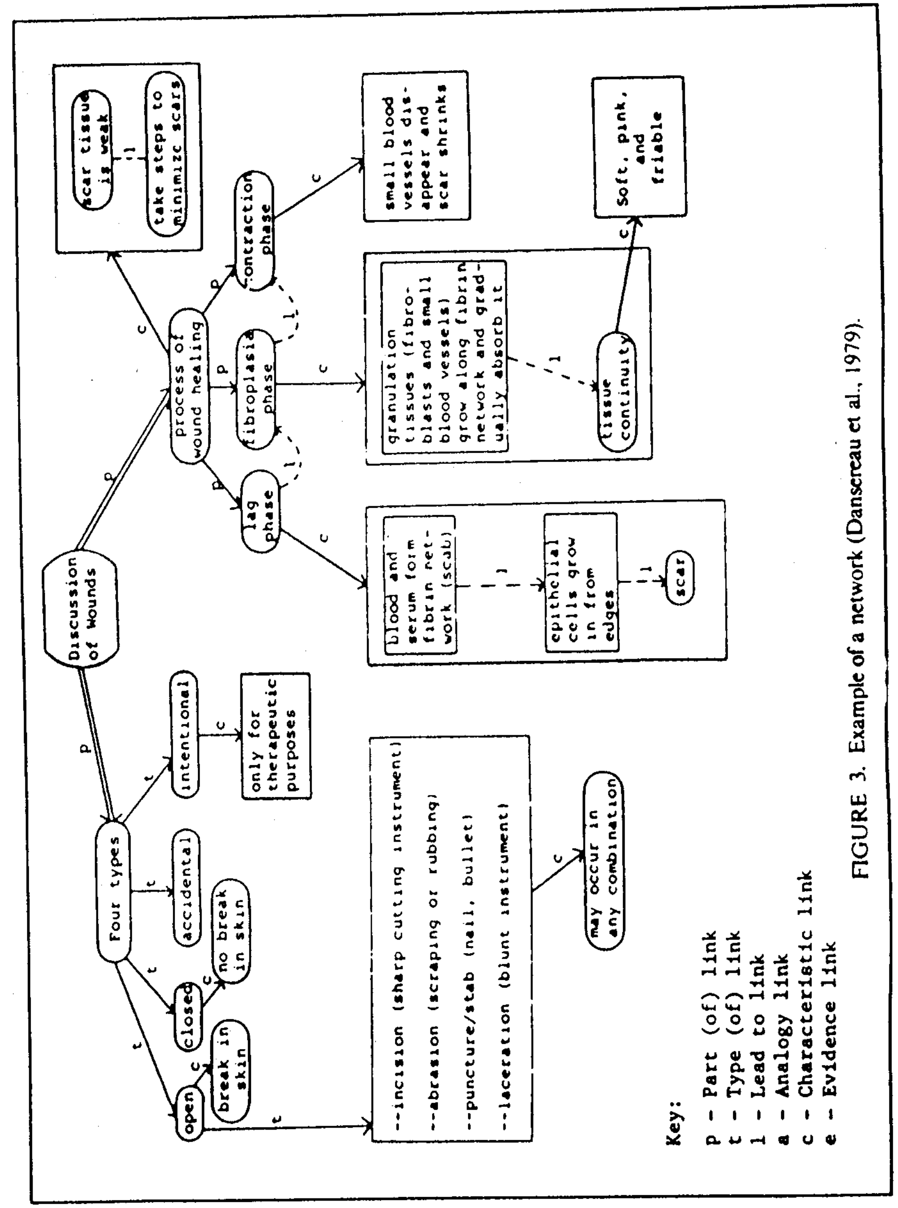

FIGURE 3. Example of a network (Dansereau et al., 1979).

general notion?" (1978, p. 15). Further, a teacher-made network can be used as an advance organizer and an incompleted network can be used to assess the student's level of comprehension as an exercise or test.

In evaluating his networking technique as an aid to comprehension, retention, and retrieval, Dansereau and his associates (1979) conducted a study in which 17 college students were trained 5½ hours to learn how to do networking. They were then given a passage to study and make a network on, while a second group of students (the control group) were asked to use their normal methods to study the passage. Five days later, students were allowed to review the notes they made during the previous sessions and were given a series of tests (multiple-choice; cloze, where students were required to fill in important concepts deleted from a paragraph summarizing the passage; short answers; and essays). A factor analysis on the different tests showed that the multiple-choice and short-answer tests were highly related to one factor, labeled *details*, whereas the cloze and essay tests were highly related to another factor, labeled *main ideas*. Analyses based on the two dependent measures indicated that the networking group performed significantly better than the control group on the main ideas. That is, the larger differences between the groups were on the essay and summary cloze tests, which assessed retention of the main ideas. No significant differences were found between the groups on the multiple-choice and short-answer tests, which assessed the details associated with the main ideas. This suggests that having students network the structure of a subject helps them remember and retrieve the major ideas of that subject.

An interesting interaction was found on the details measures between grade point average (GPA) and treatment. Results showed that for low GPA students, the networking group outperformed the control group significantly, whereas for high GPA students, the reverse held. No such interaction was found on the main ideas measure. Dansereau et al. suggest that it is possible that the high GPA students "already had effective learning strategies prior to training," and therefore were "less motivated to learn the new technique and, may have found it more interfering because of its competition with their typical approaches." Nevertheless, an important implication from this study is that a synthesis activity of this sort seems to greatly help students learn, especially low achievement students. This study supports the notion that knowledge of content structure is an important *vehicle* for learning content.

Mapping

A similar technique for synthesizing ideas is called *mapping*, which came from the work of Hanf (1971). She suggests that mapping can serve as a substitute for notetaking and outlining. According to Hanf, a map is a "graphic representation of the intellectual territory traveled, or to be traveled via reading" (p. 225). To make a map, students first locate the main idea of the text, then locate the secondary categories or principal parts that support the main idea. After labeling these parts, they can then connect them with the main idea. The map is usually concentric, with main idea in the middle and the supporting ideas around (see Figure 4). A close examination of the technique reveals that Hanf used it primarily for mapping the structure of a *text* rather than the structure of a subject matter. It serves as a reading aid to help students grasp the *organization* of the text as opposed to knowledge about content relationships.

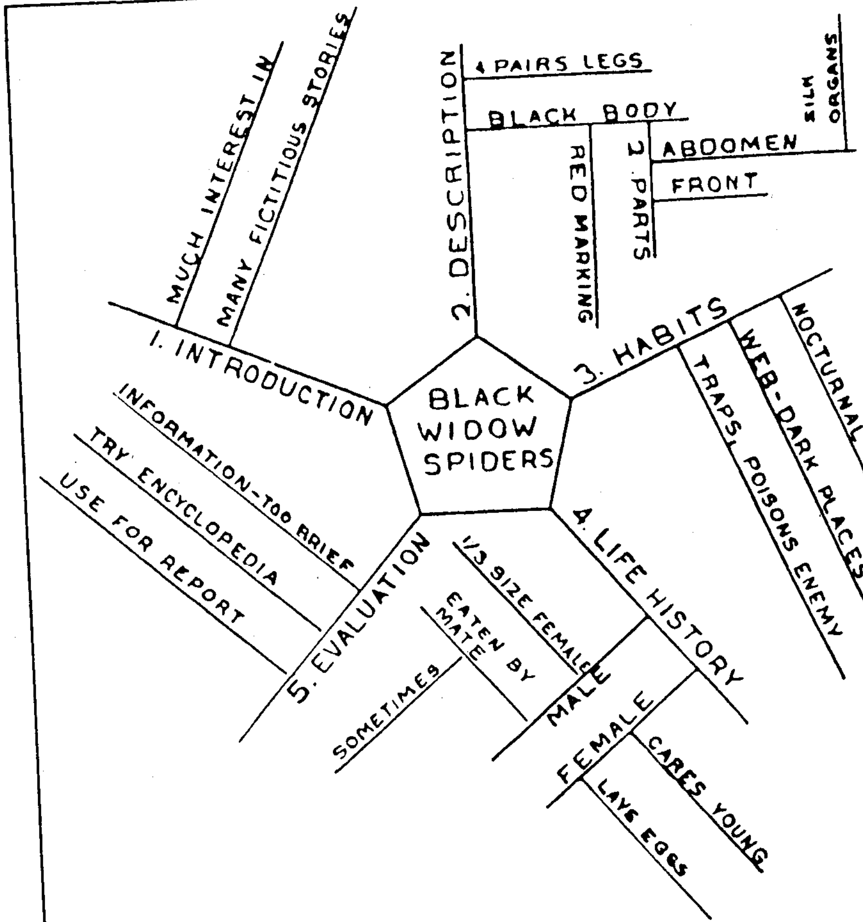

FIGURE 4. Example of a map by Hanf (1971).

Following Hanf's idea, however, came another mapping scheme developed by T. Anderson (1979), which focuses the use of mapping on describing the relationships among ideas within a subject. Anderson identified seven fundamental relationships between two ideas A and B: B is an instance of A, B is a property or characteristic of A, A is similar to B, A is greater or less than B, A occurs before B, A causes B, and A is the negation of B. He also proposed two special relationships that show when A is an important idea or when A is a definition.

Like networking, to use Anderson's mapping technique students must be trained to create a map by using a set of conventions or symbols that describe how two ideas are related. The use of conventions to describe relationships is, however, different from Dansereau's networking in that the nature of each relationship is reflected in the symbol used; therefore, no words are needed for the link between each two ideas as in a network (see Figure 5).

Anderson advocates the use of mapping as a postinstructional activity for the students to enrich the learning experience and to enhance retention of that learning. Therefore, he also sees mapping as a *vehicle* for learning content. Not much research, however, has been done to provide empirical evidence to support or refute that claim.

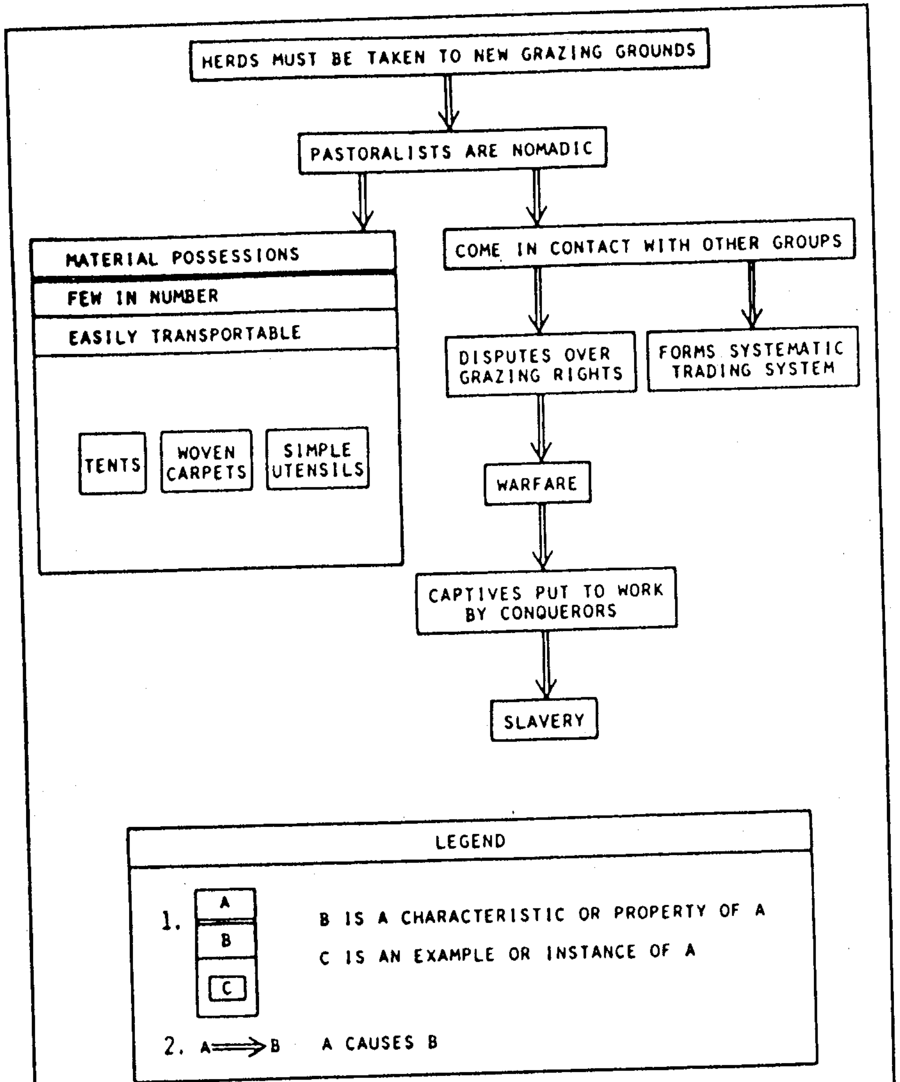

FIGURE 5. Example of a map from Robertson (1977) text.

Concept Mapping

Another strategy developed along the same line is called "concept mapping." It is theoretically based in cognitive learning, and draws mainly from Ausubel's learning theory (Moreira, 1979; Novak & Gowin, 1982; Stewart, Vankirk, & Rowell, 1979). This strategy has so far been primarily used and investigated in science teaching. A concept map is a two-dimensional diagram representing the conceptual structure of a subject matter. To construct a concept map, one first identifies the concepts, principles, and so on to be taught. Then the content elements are arranged in a hierarchical order from general to detailed, top to bottom. Finally, a line is drawn between each two related elements to show the linkage (see Figure 6).

The concept-mapping strategy can be used for two purposes: the design of instruction and the evaluation of student performance (Stewart et al., 1979). Initially, it was difficult to use concept mapping as a design tool because the nature of the relation between each two elements was not explicitly explained on the

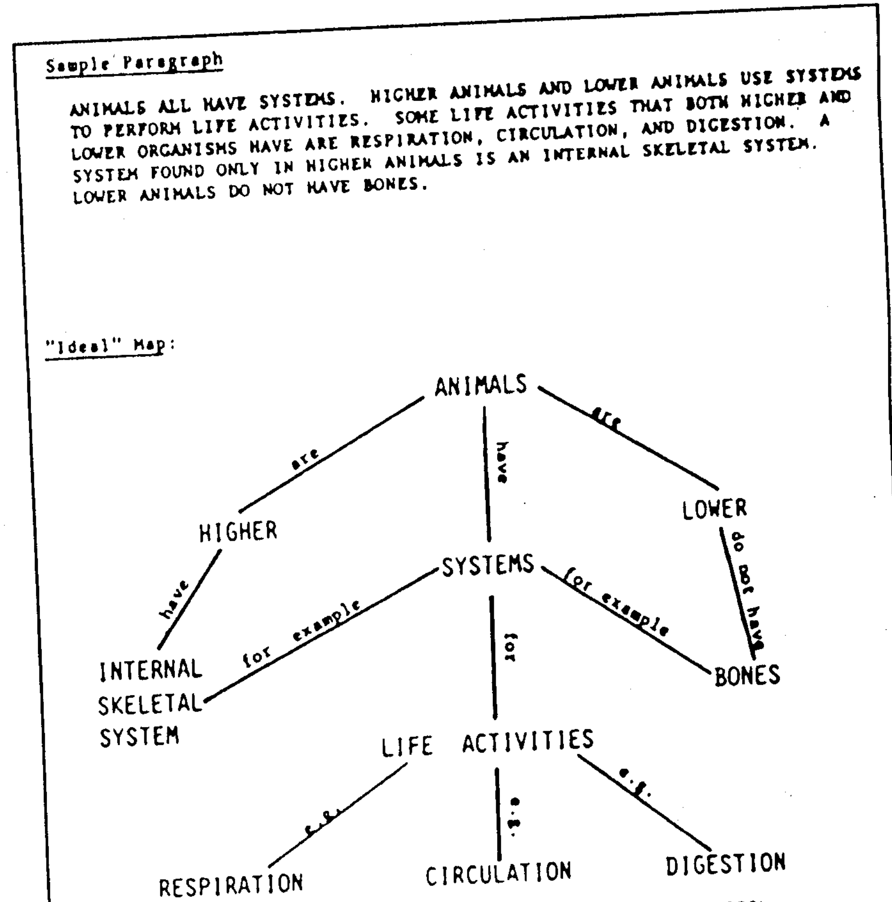

FIGURE 6. Example of a concept map (Novak et al., 1983).

diagram. Therefore, not only is it difficult for a person to thoroughly understand the whole picture, different people may interpret the lines differently. Novak and his staff later recognized the importance of labeling the lines and suggested that map makers do so.

When map construction by students is used as an evaluation tool, misconceptions in students' cognitive structures can be spotted, as well as new perspectives that emerge as a result of their creative thinking. Research studies on concept mapping have not shown definite results, although some did seem to reveal that concept maps can facilitate transfer learning and problem solving (Novak & Staff, 1981; Novak, Gowin, & Johanse, 1983).

Networking and mapping are useful techniques for synthesizing information. However, difficulties exist in making good use of them. First, students have to be trained for hours before they can proficiently use these techniques. Secondly, many types of relationships (conceptual, propositional, procedural, cause-effect, factual, etc.) are present simultaneously and linked by intertwined lines and words. These make it difficult for students to use or read the map during learning. Besides, it is not easy for students, when studying a new text, to identify all the important relationships of different natures and map them meaningfully. Consequently, some of the information is left out, as Stewart et al. (1979) commented, "... the lines chosen to link concepts on a map are the 'superhiways'; the unpaved alternative routes are less likely to be illustrated" (p. 174).

Synthesizer

Given that requiring students to draw a map or network is very often an inefficient use of student time, Reigeluth and Stein (1983) suggest a synthesizing strategy—synthesizer—to be developed as an instructional aid by designers, although it could also be developed by each learner.

According to Reigeluth, the purpose of the synthesizer is to *relate* and *integrate* the individual ideas of a *single* type of content (i.e., concept, principle, or procedure), in order to teach explicitly the interrelationships among these ideas to the learners. The synthesizer is hypothesized to have the effects of providing students with valuable knowledge, facilitating a deeper understanding of the individual ideas, increasing the meaningfulness and motivational effect of new knowledge, and increasing retention. Therefore, Reigeluth believes that teaching the relationships not only can help students learn the subject but is valuable in its own right since it provides knowledge that is not contained in individual pieces of content.

In his Elaboration Theory, Reigeluth provides a set of guidelines for constructing and testing the effects of synthesizer. When developing a synthesizer, Reigeluth suggests that the teacher should stick to a single type of relationship (conceptual, procedural, or theoretical) "so as not to confuse students as to what kind of relationship is being depicted by any given line in the diagram" (Reigeluth & Stein, 1983, p. 359). With regard to the composition of a synthesizer, he proposes that a synthesizer should consist of a *generality* in the form of a subject-matter structure for the organizing content; a few integrated *examples*; and a few integrated, diagnostic, self-test *practice* items. The generality in a synthesizer is one or more subject matter structure(s) plus the necessary verbal description to clarify their meanings (Reigeluth, Merrill, & Bunderson, 1978; Reigeluth & Stein, 1983). Each example in a synthesizer portrays the interrelationships among prototypical in-

stances of the ideas. The practice in a synthesizer is a set of new items on the interrelationships among the ideas (Reigeluth & Darwazeh, 1982; Reigeluth & Rodgers, 1980; Sari & Reigeluth, 1982).

Since the theory advocates the use of single content orientation in designing instruction, depending on the instructional objective, a synthesizer can focus on the conceptual structure (part or kind relationships; see Figures 7 and 8), the theoretical structure (cause-effect relationships; see Figure 9), or the procedural structure (sequential relationships; see Figure 10) of a subject matter. Two kinds of synthesizers were identified by Reigeluth: a lesson synthesizer, which shows the relationships among ideas within a single lesson; and a set synthesizer, which shows

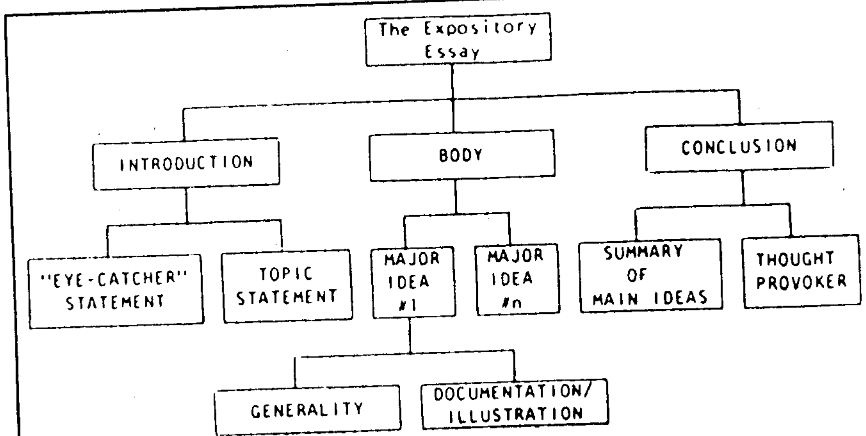

FIGURE 7. Example of a parts conceptual synthesizer-generality (Reigeluth, 1983).

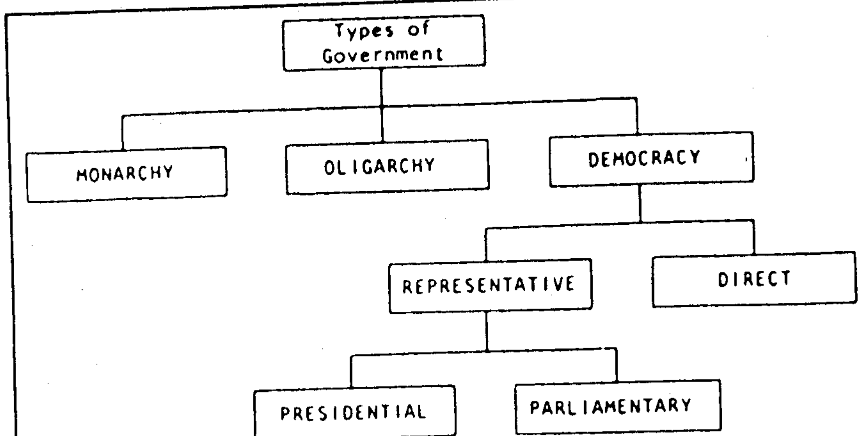

FIGURE 8. Example of a kinds conceptual synthesizer-generality (Reigeluth, 1983).

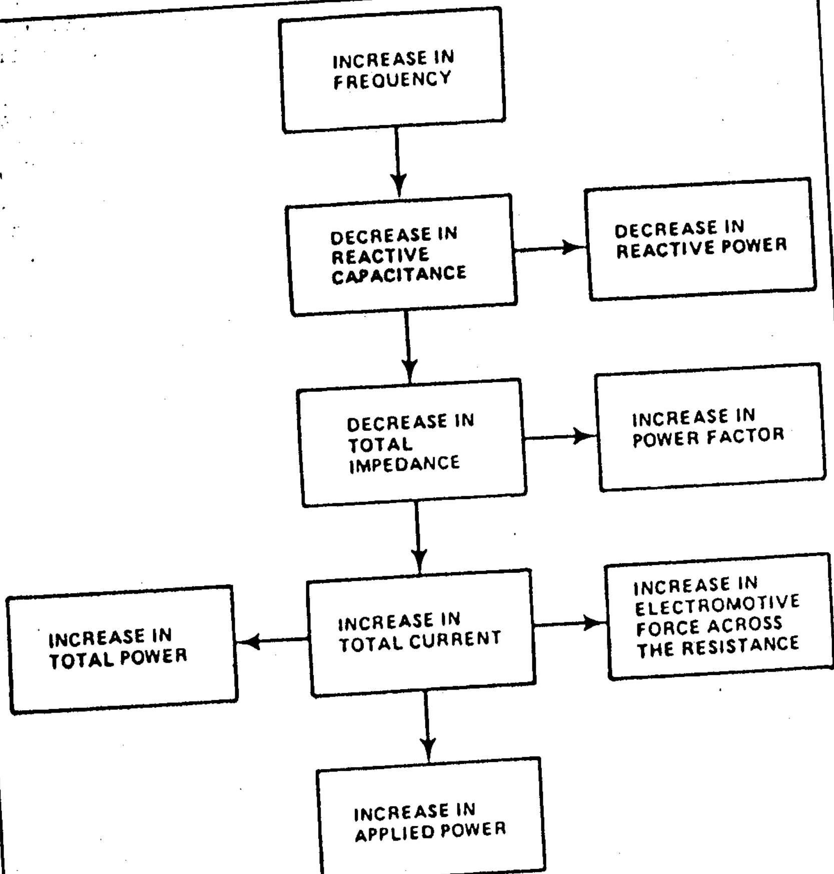

FIGURE 9. Example of a theoretical synthesizer-generality (Reigeluth, 1983).

the relationships among ideas across all lessons. It is suggested that both lesson and set synthesizers be placed at the end of the lesson.

The Elaboration Theory provides a framework within which research on synthesis can be conceptualized. However, not much research has been done so far to provide empirical support for its prescriptions. Among the few studies is one conducted by McLean, Yeh, and Reigeluth (1983). They investigated the effectiveness of three different formats of conceptual synthesizers on the acquisition of concept definitions and relationships among the concepts. The three formats were: tree-chart diagram (visual-only), prose form (verbal-only), and tree-chart and prose together (visual-verbal combination). The results suggest that when teaching conceptual relationships to high school students, a tree-chart diagram is superior to either verbal format or visual-verbal combination. The synthesizer they developed was a lesson synthesizer, according to the Elaboration Theory, since only one hour of instruction was included.

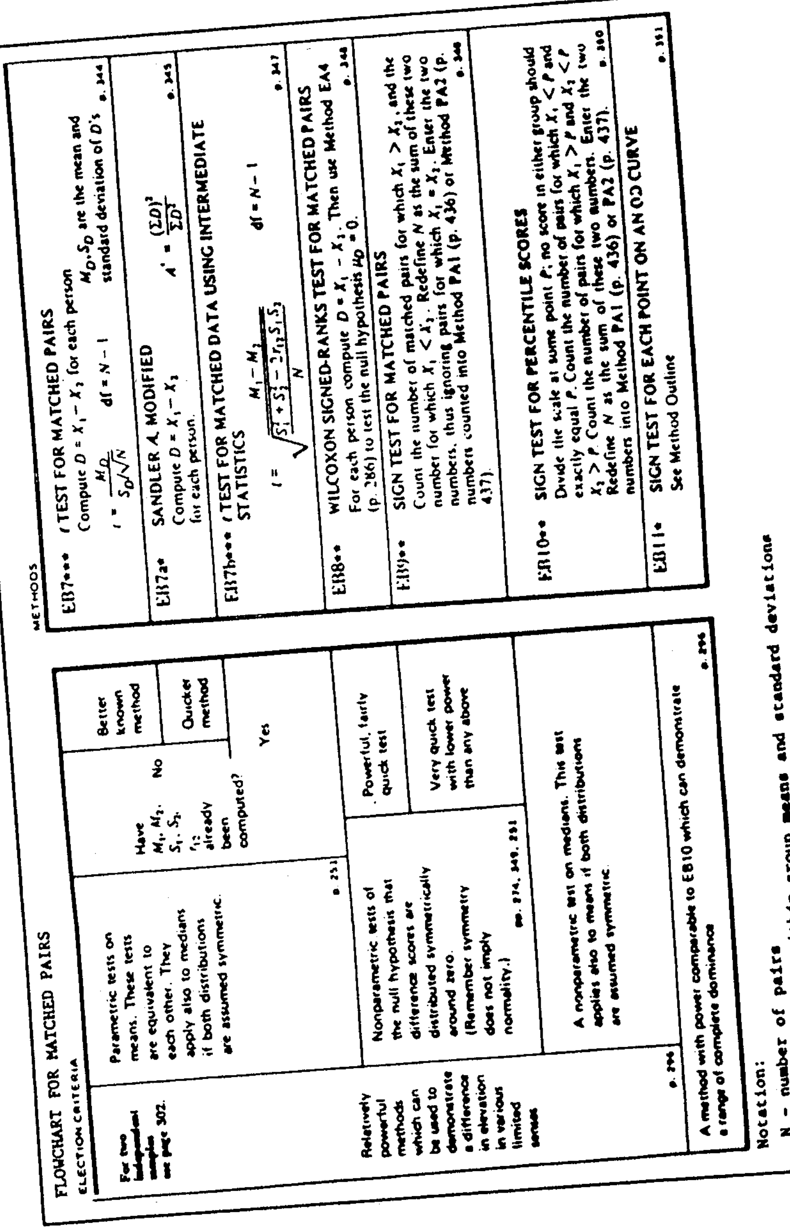

FIGURE 10. Example of a procedural synthesizer-generality (Darlington, 1975).

Following that, Chao and Reigeluth (1984) conducted a study using college students, which investigated the effects of different formats and structures of a procedural synthesizer. A set synthesizer was developed that covered 13 lessons—approximately 78 hours of instruction. The two different formats were visual (box-chart) versus verbal (prose); the two different structures were complete (generality, examples, and practice) versus partial (generality only). In testing the effects of the four combinations of format and structure on remember and application levels of learning about statistical procedures, they found that the format of a procedural synthesizer (box-chart vs. prose) did not make a difference in learning procedural relationships, whereas the structure of the synthesizer (generality-example-practice vs. generality only) did make a difference. The results suggest that a complete structure, as the Elaboration Theory prescribes, does result in better performance on remember-level learning. However, no such effect was found on application-level learning, possibly due to the students' familiarity with and ability in application, since they had been learning at that level for almost a whole semester. The authors suggested that more research needs to be done in five areas: the effects of synthesizer format for different content types, the optimal amount of content coverage for a set synthesizer, the frequency for providing a synthesizer, the structure of the synthesizer, and the types of learning outcomes on which synthesizers have the most impact.

Summary

It has been suggested that teaching the structure of a subject matter has great value in aiding the learning process as well as in its own right. It has also been suggested that teaching specific skills without making clear where they stand in a broader context of knowledge gives students less than a complete understanding of the content. Also, without knowledge of structure, specific skills are likely to be forgotten due to the lack of a structuring framework that meaningfully ties them together. Further, not only can learning outcomes (acquisition, transfer, etc.) be improved by knowledge of structure, but learning motivation can also be enhanced. Bruner (1960) suggested that the more one has a sense of the structure, the more densely packed and longer a learning episode one can go through without fatigue.

However, exactly what instructional designers must do to teach the structure has not been operationalized well in the past. In fact, theory construction and empirical testing of synthesizing strategies has been largely ignored until the past 10 years. What can be said now is that early strategies, such as advance organizers, did not serve the real purpose of synthesis (i.e., to provide knowledge of subject matter structure) although some synthesis often resulted. Later strategies, such as mapping, networking, and synthesizers, seem more promising, but lack sufficient theoretical development and empirical support. It is assumed that many instructional variables, such as content type, delivery medium, and student ability, can impact the prescriptions regarding the amount of coverage, structure, frequency, timing, and format of a synthesizing strategy. Thus, a much more refined and tested theory is required before instructional practitioners can see the benefits synthesis is assumed to provide.

Review of Sequence/Synthesis Interactions

As noted in the previous section, because synthesis research did not employ a consistent definition of synthesis, its results are not comparable. Therefore, the literature that investigates the interaction between sequence and synthesis also suffers from this problem. However, some interactions have appeared that warrant discussion.

The first such interaction was noted by Grotelueschen and Sjogren (1968). In a series of two concept attainment experiments using Ausubel's sequencing and synthesis strategies they found that "introductory materials can facilitate the learning and transfer of a number base concepts" (p. 200). However, they also found that the effects of the organizer seemed to be affected by the nature of the sequence. That is, the group given a partially sequenced treatment and an organizer scored higher on the posttest and transfer test than the groups given a randomly sequenced or correctly sequenced treatment and an organizer. "Introductory materials," they conclude, "can facilitate the transferability of experimentally learned material, especially if the material is only partially sequenced" (p. 210). In testing this hypothesis, Mayer (1978) found that an advance organizer results in greater learning when the instructional material was sequenced in random order than when sequenced in logical order. Mayer suggests that,

> if the content and instructional procedure already contained the needed prerequisite concepts . . . or tended to elicit these concepts from the learners . . . then advance organizers would not be effective. Examples include spiral instruction that presents key concepts and builds on them . . . . (Mayer 1979b, p. 375)

It is interesting to note that Grotelueschen and Sjogren (1968) used the organizing principle of general-to-detailed to construct the "appropriate" sequence and that Mayer (1978) used a part-to-whole principle for his logical sequence. Yet in both studies the organizer seemed to contribute more to learning if the sequences were deficient than if they were correct. Similarly, Schumacher, Liebert, and Fass (1975) and Lesh (1976) found that advance organizers seem to compensate for poorly integrated text. What links all these studies together is that in each case a "correct" sequence seemed to facilitate *integration* of the ideas enough that the organizer contributed no additional synthesis.

"Correct" sequences, then, which in and of themselves seem to facilitate *synthesis*, should be investigated as alternative synthesizing strategies. However, the attributes of a correct sequence that are responsible for this synthesis are unclear. Mayer (1978) and Lesh (1976) suggest that the prerequisites that elicit the appropriate learning set provide the same type of synthesis as an organizer. Schumacher, Liebert, and Fass (1975) suggest that transition phrases built into the text are responsible. An alternative explanation is that certain characteristics of the sequence might provide intermediate synthesis by implying or directly stating the relationships among the content elements as they are presented. For example, a part-to-whole sequence might be constructed so that the relationships between the "parts" are made explicit as the "whole" is pieced together. Similarly, in a general-to-detailed sequence, transitional phrases that illustrate the relationships of the concepts would also provide synthesis. If, indeed, comparable levels of synthesis can be achieved by either a built-in (sequencing) strategy or by the external (synthesizer) strategy, then one or the other could be used. There would, however, be no point in using both, since this would not significantly increase learning, but would add to the cost of instruction in both development and delivery time.

Frey and Reigeluth (1981) investigated the effects of various sequences and pre- and post-synthesizers. To test students' ability to use concepts, two conceptually oriented sequences were constructed: general-to-detailed and detailed-to-general. In addition, three levels of syntheses were included: pre-, post-, and absent. These three syntheses were crossed with the two sequences to yield six treatment groups. Though no main effects were found on a test of use-level outcomes, Frey and Reigeluth did find a significant interaction: (a) The pre-synthesizer worked best with the detailed-to-general sequence, and (b) the post-synthesizer worked best with the general-to-detailed sequence. These findings seem to contradict those predicted and found by Ausubel. That is, a pre-synthesizer (advance organizer) seemed to facilitate use-level outcomes but only when used with a detailed-to-general sequence. For post-synthesizers, the reverse was true: Post-synthesizers facilitate use-level outcomes but only when they were used with a general-to-detailed sequence.

Frey and Reigeluth (1981) suggest that when material is presented using a general-to-detailed sequence, "the most general concepts themselves provide the context for the subsequent concepts, such that students do not benefit from a synthesis as an initial overview . . ." (p. 5). With a detailed-to-general sequence, where the initial general concepts are absent, students do benefit from a synthesis as an initial overview. This explanation is consistent with those of Mayer (1978), Schumacher et al. (1975), and Lesh (1976), who suggest that there are redundant effects between built-in syntheses guided by correct sequences and external syntheses guided by organizers or synthesizers. However, Frey and Reigeluth caution that these results may only apply to syntheses constructed for conceptual content. Further research, therefore, should test their results using other types of content as well.

Summary

Although there has been little research on sequence/synthesis interactions, it is, nevertheless, an area that is worth exploring. Based on the results from Frey and Reigeluth's study it seems important to consider the position and timing of synthesis in relation to the particular sequencing strategy and content orientation that is employed.

Conclusion

The micro strategies of instruction seem to be the building blocks of instructional design. Instructional researchers have identified the required elements and general principles for effective micro sequencing. Future research might best focus on how to make micro instruction more efficient.

The role of macro strategies in instruction is not well-understood. Nor is the agenda of macro strategy research. Perhaps the greatest impediment to progress in this area of research is the lack of consistent terminology, and models or theories that can be tested. Though Posner and Strike (1976) present a useful scheme for classifying instructional sequences, it has never been used as an aid to empirical research. Similarly, Elaboration Theory (Reigeluth & Stein, 1983) offers a set of models for macro instructional design, including specifications for sequencing and synthesizing, but little research has been conducted.

The current problems stemming from the lack of consistent terminology, models, and theories are made more acute when computer-based delivery systems are taken into account. For example, with the computer as a delivery medium, instruction need not be defined as a set of linear events. Rather, it can be imagined as a structured organization of data types with an accompanying set of rules for its use by students. Entirely new macro strategies may need to be created, which include definitions and prescriptions for strategies such as "interactivity" or "online help."

It is recommended that future research in instructional sequencing and synthesizing focus on the development and validation of implementing strategies based on a common language and a set of models and theories, and at the same time give attention to various types of content, instructional outcomes, and delivery systems.

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